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HMX AS A MILITARY EXPLOSIVE

1 OCTOBER 1956

U. S. NAVAL ORDNANCE LABORATORY

WHITE OAK, MARYLAND

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HMX AS A MILITARY EXPLOSIVE

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ABSTRACT: The purpose of this report was to collect the available data on the experimental explosive HMX and to compare its explosive performance, chemical and physical properties and cost of manufacture to those of the very similar standard explosive RDX and arrive at some conclusions as to the value of HMX as a military explosive. The explosive performance has been compared not only to that of RDX but also to that predicted for HMX in order to see if the performance observed was in agreement with prediction. The following conclusions were reached:

In the optimum compositions, HMX would offer in good agreement with predictions a 11-12% improvement in plate acceleration, shaped charge penetration, fragmentation and as a base charge in detonators, but no significant improvement in airblast or underwater performance. In addition HMX possesses a modest advantage in stability at elevated temperatures which may be important in such problems as "cook-off" and aerodynamic heating. These gains can be achieved only at an increased cost of about 250% over that of the standard explosive RDX. Selected portions of the pertinent data are reproduced and some specific applications are considered.

EXPLOSIVES RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
White Oak, Silver Spring, Maryland

NAVORD Report 4371 1 October 1956

This report describes the evaluation of the experimental high explosive HMX from available data. Points of superiority over the best standard high explosive RDX are discussed and matched against estimates of manufacturing costs. This study was made at the request of the New Explosives Committee and the Chief, Explosives Research Department, U. S. Naval Ordnance Laboratory under Task NO 800-667/76004/01040. The validity of the study and of the conclusions and recommendations presented are the responsibility of the author and the Chemistry Division, NOL.

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Captain, USN
Commander

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J. E. ABLARD
By direction

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HMX AS MILITARY EXPLOSIVE

A. INTRODUCTION

HMX is an experimental high explosive very similar chemically to the standard military explosive RDX. It differs chiefly in possessing a higher crystal density than the latter, which offers an advantage in special applications on an equal volume comparison. Thus it has often been suggested in the last three years as an improvement over RDX in certain formulations.

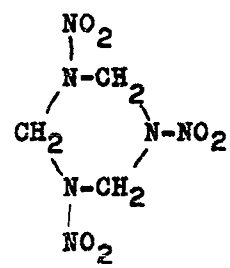
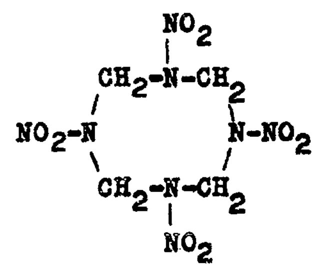
The purpose of this report is to collect the available data on its explosive performance, physical and chemical properties and cost of manufacture, and to compare them with those of RDX and arrive at some conclusions as to the military value of HMX as a new explosive.

Prior to 1954 the very limited availability of HMX precluded its extensive evaluation, but since then reasonable quantities have become available as a result of extensive pilot plant development work at Picatinny Arsenal (1) and Holston Ordnance Works (2,3,4,5), with the result that a more complete evaluation has been performed upon it. It is probably timely to examine the results to date and reach some decisions as to the gain in performance to be expected in various applications as balanced against the need for such gain and the cost involved. Other factors than performance are worth considering at this time, such as physical properties of compositions, as well as their safety, storage stability and resistance to high temperatures.

Therefore, at the request of the New Explosives Committee, and the Chief, Explosives Research Department, NOL, the pertinent data have been examined from this viewpoint and compared to predicted effects.

B. COMPARISON OF CHEMICAL AND PHYSICAL PROPERTIES

(Data are from NOL unless otherwise referenced.)

	RDX	HMX
Formula	 $C_3H_6N_6O_6$	 $C_4H_8N_8O_8$
Molecular Weight	222.13	296.17
Melting Point (Dec.)	205°C (6)	275°C (6)
Explosion Temp. (5 sec.)	260°C (7)	327°C (7)
Vacuum Thermal Stability	(100°C)0.10 (7)	0.10 (7)
(cc gas/g in 48 hrs.)	(150°C)3.0 (7)	0.60 (7)
	(180°C)13.2 (NOL)	---
Confined "Cook Off" Temp.	180°C (8)	210°C (8)
Hygroscopicity	nil (7)	nil (7)
Crystal Density	1.802	1.903
Crystal Forms	Two: 1-stable, 1-metastable (6).	Four: 1-metastable, 1-stable to 146°C, 1-stable 146-158°C, 1-stable>158°C (6).
Crystal Hardness (Mohs)	2.4 (9)	2.3 (9)
Specific Heat (cal/g/°C)	0.30 (10)	---

B. COMPARISON OF CHEMICAL AND PHYSICAL PROPERTIES, Contd.

Formula	RDX	HMX
Heat of Combustion (kcal/mole)	501.82 (11)	667.41 (11)
Heat of Formation (kcal/mole)	-14.71 (11)	-17.93 (11)
Heat of Detonation (calc) (H_2O gas) cal/g	1228 (12)	1222 (12)
Heat of Explosion (calc) (H_2O liq) cal/g	1362 (12)	1356 (12)
Chemical Reactivity	Slowly attacked by boiling dilute acids and alkalies. (7)	Same, but at a much slower rate. (7)

In summary it would appear that the only significant differences in these properties are the slightly higher density of HMX and its somewhat better resistance to high temperatures, as typified by superior cook off temperature (30°C better), explosion temperature (70°C better), and vacuum stability at 150°C. The heat of explosion per gram is the same for both but the higher density gives HMX a 5-1/2% advantage on a volume basis.

C. PREPARATION AND COSTS

Both of these explosives are prepared by the well known Bachman nitration of hexamethylenetetramine under different sets of conditions but identical equipment. The RDX procedure is too well known to discuss here (6,7,10). The HMX process has been developed through the pilot plant stage as a batch process at both Holston Ordnance Works, (2,3,4,5) and Picatinny Arsenal (1). Both have attempted to design a continuous process for its preparation. Conversations of the author with Drs. J. V. R. Kaufman and J. P. Picard of Picatinny Arsenal as to possible costs have produced the following rough estimates:

HMX - Cost per lb, FOB plant, by batch process - $1.10

HMX - Cost per lb, FOB plant, by continuous process---------------------------------- 0.75

RDX - Cost per lb, FOB plant, (Holston), present cost--------------------------------------- 0.30

Thus, HMX, while capable of being produced in present RDX production equipment, appears to be potentially about 2-1/2 times as expensive as RDX.

In summary, any application of HMX as a replacement for RDX will entail a 2-1/2 fold increase in cost per pound of explosive. This is frequently a minor cost of the weapon as a whole, but the performance gain achieved must be matched against this increased cost.

D. EXPLOSIVE PROPERTIES COMPARISON, HMX vs RDX

	RDX	HMX
(a) Impact Sensitivity, (ERL Machine, 2.5 kg wt)		
Pure Explosive	20-24 cm	26-32 cm
Explosive cast in TNT (70/30)	53 cm	47 cm
Explosive cast in TNT (60/40)	69 cm	52 cm
H-6 and Analogs (Explosive/TNT/Al/Wax-47/31/22/5)	128 cm	92 cm
Explosive/TNT/Al-55/35/10	69 cm	65 cm
Explosive + 9% Wax (Stanolind-Alox)	75-80 cm	68 cm
Sensitivity to Initiation by PbN_6	---	< RDX (10,19)
Friction Sensitivity	Fires (7)	Fires (7)
(b) Detonation Velocity (m/sec)		
1. Pure, 97% voidless density	8743 (12)	9124 (12)
slope (m/cc/sec/g)	3700#	3700#

\# There is some disagreement as to the value of this slope from different laboratories. Values from 3466 to 3700 can be found in the references, OSRD Report 5611 and the Second Detonation Symposium.

D. EXPLOSIVE PROPERTIES COMPARISON, HMX vs RDX Contd.

	RDX	HMX
2. Explosive + 9% Wax	8310 (12)	8630 (13)
(97% voidless density) slope	4310	4310
3. Explosive + 25% TNT	8330 (12)	8520 (12)
(at voidless density) slope	3290	3330

(c) Explosive Energy per unit volume (calc)

Heat of Detonation x Crystal Density ($\rho_c Q$) cal/g	2218	2322

(d) Detonation Pressure

(On the assumption that the kappa terms for RDX and HMX are practically equal, detonation pressures have been approximated by the expression ρd^2 at 97% of voidless

	Detonation Pressure (ρd^2 in kilobars)	
Pure Explosive	133.5×10^6	153.5×10^6
	($\rho = 1.745$)	($\rho = 1.842$)
Explosive + 25% TNT	113.0×10^6	125.5×10^6
	($\rho = 1.707$)	($\rho = 1.780$)
Explosive + 9% Wax	112.0×10^6	125.3×10^6
($\rho_{wax} = 0.95$)	$\rho = 1.623$	$\rho = 1.697$

In summary, pure HMX does not appear to be significantly different from RDX in sensitivity to impact or friction, but it is definitely less sensitive to shock initiation (10, 19). In compositions, however, there is a definite tendency of the HMX formulation to be slightly more sensitive to impact than the RDX ones. This is unexpected for the following reasons. The compositions compared possessed the same weight percentage of each component but differed in volume percentage as follows:

	Volume % of Explosive	Other Volume %
Explosive + 9% Wax (ρ wax = 0.9)	RDX - 83.49	Wax - 16.51
	HMX - 82.72	Wax - 17.28
Explosive + 25% TNT	RDX - 73.30	TNT - 26.70
	HMX - 72.25	TNT - 27.75

Thus the matrix of insensitive component surrounding the HMX crystals is larger on the average than in the same weight percent RDX formulation. Therefore, if the surfaces are properly wetted in each case, one would expect the HMX formulations to be less sensitive to impact whereas the reverse trend has been found. However, no work has been done on the surface chemistry of HMX. In HMX charge preparation, either no wetting agent was used, or one was selected at random which may not have been the appropriate one for HMX. Also, little work has been done on the control of particle size of HMX as it effects sensitivity, but only as to its effects on viscosity of the castable mixtures. On the other hand, a considerable amount of work on the surface chemistry of RDX has been done (22). The use of wetting agents is standard practice in all RDX charge formulations. Further, a great deal of experience is available with RDX on the control of particle size and its effect on the properties of charges.

Thus it is believed that this unexpected trend is due to lack of knowledge and experience on the surface chemistry and particle size of HMX in contrast to RDX and their effects on charge properties.

The Detonation velocity and explosive energy per unit volume of the HMX formulations is superior to the analogous RDX compositions by 4-6% as one would expect from the higher density. Detonation pressure is believed to be the major factor governing shaped charge, fragmentation, and plate acceleration performance. Here the HMX shows an 12-13% improvement at a fixed percentage of voidless density.

E. APPLICATIONS

(a) General Considerations

HMX is so like RDX in its physical and explosive properties that evaluations have largely been made by substituting it on an equal weight basis for RDX in explosive compositions. Thus analogs of Composition A, Cyclotols, HBX's, PBX's and H6, have been the ones tested. Of course, to be truly comparable these substitutions should have been made on an equal volume basis in these compositions. On this basis, the compared charges would have had the following compositions:

	Voidless Density	Wt Explosive	Wt Other
Explosive + Wax	1.67	RDX-91.0	Wax - 9.0
	1.75	HMX-91.4	Wax - 8.6
			(ρ Wax = 0.95)
Explosive + TNT	1.76	RDX = 75.0	TNT = 25.0
	1.84	HMX = 76.0	TNT = 24.0

Generally, the physical properties and castability of these mixtures appear to differ but little from those based upon RDX. Thus, in the PBX's the compressive strength of 91% RDX/9% plastic binder of 3700 psi was readily duplicated with similar techniques with the 91% HMX/9% plastic PBX composition (15). Similarly the 15 second viscosity of 75/25 Cyclotol was readily duplicated at Holston Ordnance Works with 75/25 Octol (2,3,4). Comments from the Casting House personnel at NOL to the author are that there are only slight differences in the charges cast from either. If anything, the HMX charges give fewer voids and cracks. Thus one can only state that charges prepared from HMX appear to be at least equal to those prepared from RDX but offer no significant advantage in physical properties with the limited experience to date.

(b) Comparison of Predicted and Observed Performance

Prediction of performance in airblast and underwater in the following table is based solely upon the differences between the voidless densities of the corresponding HMX and RDX compositions, as the performance is dependent on weight of charge but not loading density. Shaped charge performance is believed to be directly proportional to detonation pressure and was so predicted. Fragmentation and plate acceleration seem to be primarily governed by detonation pressure but are also affected to a small extent by other factors whose importance is not entirely clear. Thus detonation pressure alone was relied upon in these predictions also.

TABLE I

Comparison of Predicted and Observed Explosive Performance

Type of Performance	Composition	Performance Improvement	
		Predicted	Found
Shaped Charge Penetration (14) (Appendix II)	Explosive + 9%Wax	12%	7.6%
	" + 25%TNT	11%	18.5%
Plate Acceleration (17) (Appendix I)	Explosive + 9%Wax	12%	8%
	" + 25%TNT	11%	11%
Fragment Velocity (16)	Explosive + 9%Wax	12%	* No data on HMX except a vague statement of superiorty
	" + 25%TNT	11%	
Base Charge for Detonators (20,21) (Plate dent or Plate Perforation) (Appendix V)	Pure Explosives	14%	8-12%
Airblast Effects (Appendix III)	H-6 type	2.2%	No significant improvement.
Underwater Effects (Appendix IV)	HBX-1,3 types	1-2%	No significant improvement.

* Fragmentation: In spite of the lack of data on this type of performance the author believes that improved performance of 11-12% predicted by detonation pressure considerations is sound. The fact that in plate acceleration performance, which is very similar to fragmentation, the observed performance agreed well with detonation pressure predictions is good evidence for the soundness of such predictions. The superiority of HMX in fragmentation tests reported by Picatinny Arsenal by a vague reference to tests performed in 105 mm and 90 mm shells on which details could not be obtained is further evidence that this prediction is at least in the right direction (16).

F. CONCLUSIONS

(a) An improvement in performance of 8-11% can be obtained by the substitution of HMX for RDX in compositions containing 75% or more of the former in the following applications:

1. Plate acceleration.
2. Shaped charge performance.
3. Base charge in detonators (plate dent or brisance).
4. Fragmentation.

(b) An increased stability at high temperatures can be achieved by the substitution of HMX for RDX. This increase is not large but may be sufficient to overcome marginal stability of RDX charges in specific cases.

(c) An increase of about 250% in explosive cost will be incurred by replacement of RDX by HMX and must be matched against the overall gain in performance of the weapon. However, potential availability and production is as good as for RDX.

(d) There is no substantial difference in physical properties or sensitivity of most HMX charges over corresponding RDX charges. The slight differences observed in sensitivity are believed to be due to lack of knowledge and experience in charge preparations with HMX.

G. RECOMMENDATIONS

(a) In view of the cost of HMX and the gains to be expected from it, it is recommended that it be actively exploited as a replacement for RDX only in warhead compositions of costly weapons where shaped charge penetration or fragmentation is the major criterion of damage production. This might include the smaller guided missiles and perhaps some of the more costly air-to-air and air-to-surface and surface-to-air rockets and missiles where the warhead cost is only a minor fraction of weapon cost and the 11-12% improvement is well worth this increase.

(b) It is also recommended that it be actively exploited for applications of the plate acceleration principle where the 11-12% improvement is highly important and cost is of minor importance.

(c) It is recommended for use as a base charge in detonators or fuze explosive trains. The 11-12% gain in output and the greater margin of safety in heat stability could be achieved at

a cost of only a fraction of a cent per fuze. Its use in place of tetryl in fuze explosive trains should markedly improve the heat stability of such fuzes.

(d) It is further recommended for warheads where resistance to elevated temperatures is a major consideration such as serious "cook off" or aerodynamic heating problems, and where the modest improvement is both sufficient and necessary.

(e) In view of the good agreement between the explosive performance predicted from the fundamental properties of HMX and those actually measured to date, it is recommended that further experimental work on explosive performance be confined to more accurate measurements of such fundamental properties as detonation pressure and detonation velocity and the effects on these properties of the necessary additives required for practical military compositions for specific applications.

(f) In view of the observed tendency for HMX compositions to be slightly more sensitive to impact than the analogous RDX charges, it is recommended that a study be made of the surface chemistry and wettability of HMX as well as the effect and control of particle size of HMX on the sensitivity of charges prepared from it. It is understood that the current program of the U. S. Naval Research Laboratory will accomplish the former (22).

(g) It is recommended that no further consideration be given to the use of HMX in airblast or underwater warheads except in those special cases cited in recommendations above. This is based on this assumption that increases of 1-2% in performance are not worth the additional cost.

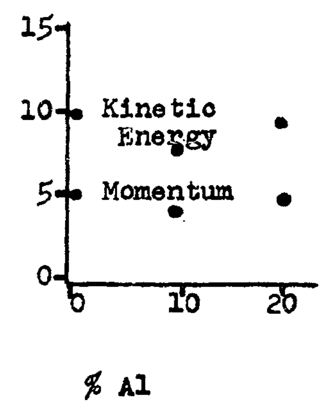
APPENDIX I

PLATE ACCELERATION (17)

Corrected to 93% of Voidless Density

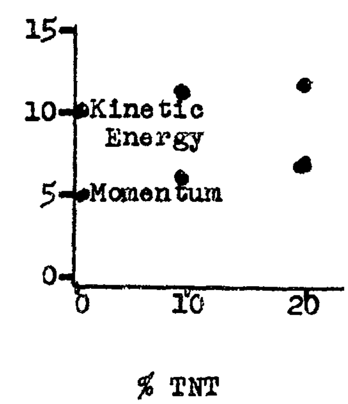
HMX/Al vs RDX/Al

% Improvement



HMX/TNT vs RDX/TNT

% Improvement



Kinetic Energy Improvement 8-9% 10-11%

APPENDIX II

SHAPED CHARGE PERFORMANCE (14)*

Composition	Charge Density ρ_o, g/cc	Voidless Density ρ_c, g/cc	% of ρ_c	Penetration* (inches of mild steel)	Cone Mfg**
RDX/Wax 91/9	1.61	1.67	96	6.06	Budd Co.
RDX/TNT 75/25	1.70	1.75	97	6.24	Budd Co.
HMX/TNT 75/25	1.80	1.83	98	7.39	U.S. Co.
HMX/Wax 91/9 Standolind	1.71	1.745	98	6.50	U.S. Co.

* With 1-5/8" diameter M9A1 Cones of steel, 44° Apex Angle Improvement at same percentage of voidless density, 7.6-18.5%.

** There is a source of error in this data which has increased the experimental error by an unknown amount. The improvement shown is probably real but not highly accurate. This occurred when the supply of Budd Co M9A1 cones was exhausted after performing the RDX tests and the new ones used for the HMX tests were procured from the United Specialties Co. These cones differed in thickness by about 10%, but no actual performance comparison was ever made between the two.

APPENDIX III

AIRBLAST PERFORMANCE (16)

Composition	Loading Density g/cc	Theor. Voidless Density g/cc	% of Voidless Density	Impact Sensitivity 50% Height in cm	PEAK PRESSURE RESULTS: EW of H-6	PEAK PRESSURE RESULTS: EV of H-6 Using Actual Loading Densities	PEAK PRESSURE RESULTS: EV of H-6 Using Theor. Voidless Densities	POSITIVE IMPULSE RESULTS: EW of H-6	POSITIVE IMPULSE RESULTS: EV of H-6 Using Actual Loading Densities	POSITIVE IMPULSE RESULTS: EV of H-6 Using Theor. Voidless Densities
RDX/TNT/Al/Wax 47/31/22/5	1.67	1.81	92.3%	101	1.00	--	--	1.00	--	--
RDX/TNT/Al/Wax 47/31/22/3	1.74	1.84	94.6%	82	0.99	1.03	1.01	0.956	0.99	0.98
RDX/TNT/Al/Wax 47/31/22/1	1.77	1.87	[illegible].6%	81	0.99	1.05	1.02	0.912	0.97	0.94
HMX/TNT/Al/Wax 47/31/22/5	1.67	1.85	90.3%	92	0.97	0.97	0.99	0.922	0.92	0.94
HMX/TNT/Al/Wax 47/31/22/3	1.76	1.89	93.1%	77	1.00	1.05	1.04	0.942	0.99	0.98

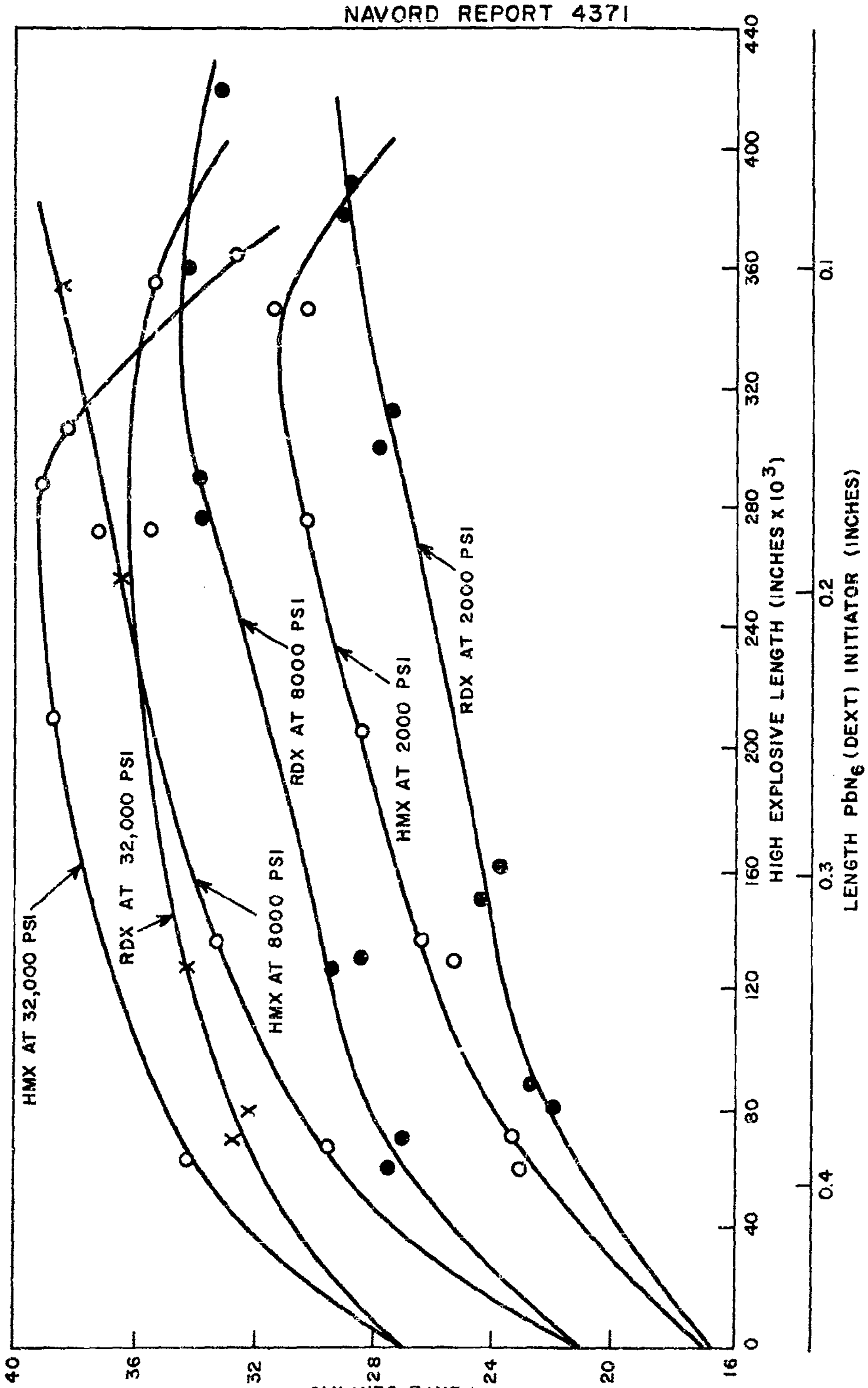
Estimate of the precision (standard error) for EW value is ± .02 for pressure results and ± .04 for positive impulse results.

APPENDIX IV

UNDERWATER PERFORMANCE (17)

Composition	Shock Energy		Bubble Energy	
	Equal Wt.	Equal Vol.	Equal Wt.	Equal Vol.
RDX/TNT/Al/Wax				
40/38/17/5 (HBX-1)	1.00	1.00	1.00	1.00
31/29/35/5 (HBX-3)	.91	0.96	1.32	1.40
HMX/TNT/Al/Wax				
40/38/17/5 (HBX-1) (analog)	1.02	1.05	1.00	1.03
31/29/35/5 (HBX-3) (analog)	.93	1.00	1.31	1.40

APPENDIX V



DETONATOR BASE CHARGE PERFORMANCE, HMX VS RDX
USING PLATE DENT TEST

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Wright Air Development Center Wright-Patterson Air Force Base Dayton 2, Ohio Attn: Aeronautical Research Laboratory Chemistry Branch, L. A. Wood, Chief	1